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# Replica molding: Complex optics at lower costs

New molding techniques offer flexibility in design and manufacture.

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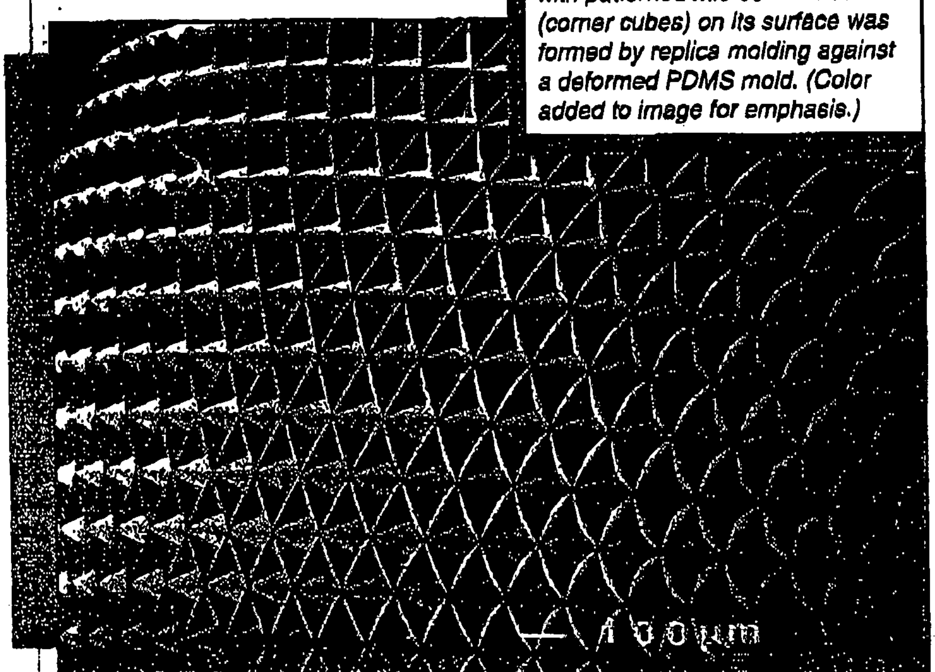
At Harvard University's Department of Chemistry, we are exploring new ways of fabricating complex, optically functional surfaces, components and devices using elastomers as starting materials. The main elastomer used is poly(dimethylsiloxane) (PDMS), which is isotropic, noncrystalline, chemically inert and optically transparent down to ~300 nm.

PDMS replicas with patterned relief microstructures (for example, diffraction gratings) on their surfaces are easily fabricated by replica molding. In the process, a liquid prepolymer of PDMS (Dow Corning's Sylgard 184) is poured over rigid masters whose surfaces have been patterned with complementary structures using microlithographic techniques. After curing the prepolymer to a solid, the PDMS replicas are carefully peeled from the masters.

Replicas with microstructures on their surfaces can be directly used to construct elastomeric, optically functional components and devices whose characteristics can be controlled, in real-time, by modifying their structures using mechanical compression or extension. We have developed a number of examples including lenses, mirrors, diffraction gratings, photothermal detectors, phase modulators and light valves. These deformable optical components have potential applications in adaptive optics, display devices, sensors and photolithographic systems.

The PDMS replicas work as molds in micromolding procedures for fabricating patterned micro/nanostructures of other polymeric materials. For example, using micromolding in capillaries (MIMIC) and microtransfer molding (μTM) we have fabricated polymeric, single-mode optical waveguides several centimeters long.




*This scanning electron micrograph of a dome-shaped polymeric object with patterned microstructures (corner cubes) on its surface was formed by replica molding against a deformed PDMS mold. (Color added to image for emphasis.)*

## Elastomeric molds

Replica molding of an organic polymer (such as UV-curable polyurethanes or thermally curable epoxies) against an elastomeric mold, while this mold is under mechanical deformation, provides routes to complex optical surfaces that would be impractically difficult to generate using other techniques. Deformation of the elastomeric mold occurs isotropically; simple and regular patterns/structures present on a planar surface can be easily transformed into topologically and spatially complex structures in the replica with good preservation of optically relevant characteristics.

Using this procedure we have produced chirped, blazed diffraction gratings on planar/curved surfaces, and patterned microfeatures on surfaces of approximately hemispherical objects. Compression can also be used to reduce feature sizes on the mold; for example, from 50 to 30 nm or even from 2 μm to 200 nm.




Replica molding against an elastomeric mold offers a practical way to manufacture nanostructures. Expensive, high-resolution lithographic techniques (for example, e-beam writing and x-ray lithography) could be used to make masters, and copies of these nanostructures could then be replicated into organic polymers.

Elastomers will have broad application in applied optics. Because an elastomeric surface's structure can be deformed in many different ways, a single PDMS replica can be easily adapted to several applications. Replica molding against elastomeric rather than rigid molds provides a convenient, low-cost and practical route to new optical surfaces and structures.

The elastomeric character of the mold enormously increases the ease of separating the mold and the replica, minimizes damage to the mold and protects fragile structures during separation. It also allows us to modify and control the size and shape of features present on the mold using mechanical deformation. In order to find applications in binary optics, however, we need to correct for shrinkage of polymer and distortion of mold, and carefully evaluate the performance of formed optical surfaces in the future. □

# Micro-opto electromechanics

## Could revolutionize photonic systems

A promising team-up of three technologies broadens the field for optical systems.

by Ed Motamedi, Senior Scientist
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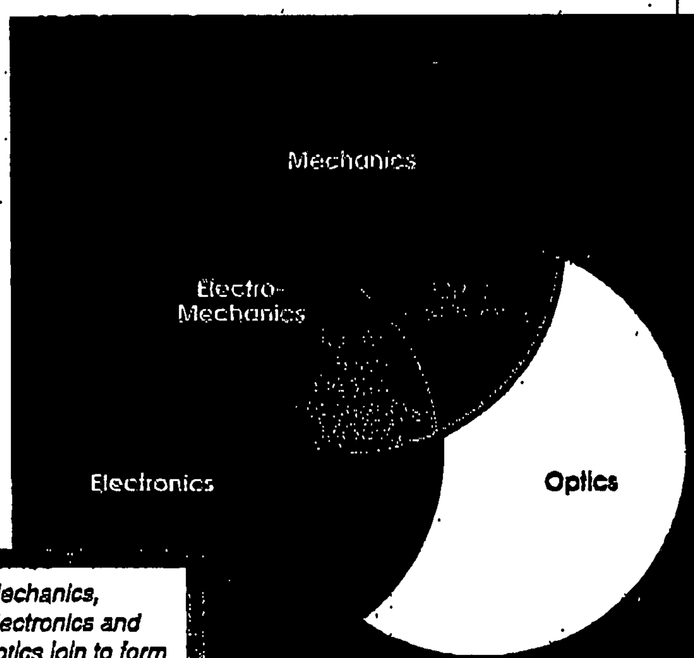
Advances in micro-optics have led to the development of large-volume and batch-processed diffractive and refractive micro-optical components, creating an emerging technology that promises to revolutionize many photonic systems.

This is an enabling technology for applications not readily addressed by conventional optics. Similar to micro-optic technology, micro-optic electromechanics (MEM) provides a powerful tool for miniaturization of mechanical systems into a dimensional domain that is not accessible by conventional machining. A number of companies in the US and abroad are beginning to channel significant efforts into exploiting the technology.

### An impact on industry

Using MEM to create a broader class of devices will affect the industrial use of micro-opto-electromechanical (MOEM) devices further and will lead to the development of commercial products such as laser scanners, focal plane arrays, dynamic micromirrors, digital videos and optical crossbar switches.

This technology should also spawn high-performance devices for microsensor systems that are lighter, easier to produce, more efficient and less expensive than conventionally manufactured components. MOEM systems will open a new technology avenue for a large class of commercial optical systems that have been ignored in the past because of the limitations of bulk optics and actuators. Both constituent technologies in MOEM allow for batch processing and embossing, which opens the door to a fascinating array of commercial applications.




*Mechanics, electronics and optics join to form micro-opto-electromechanics.*

Recent developments in micro-optics and the miniaturization of optical components, such as binary